REMARKS

Claims 20-22, 24 and 27-49 are pending in this application. By this Amendment, claims 20-22, 24, 27, 28, 30-32 and 37-49 are amended, without narrowing, for clarity. The amendments emphasize the definition of "dopant" as an additive that controls resistivity in a silicon single crystal, as suggested by Examiner Anderson at the July 1, 2003, personal interview. Support for these amendments can be found in the original claims and the specification as filed, for example, at page 6, lines 16-19.

The courtesies extended to Dr. Abe, Mr. Tsuda, Mr. Yoshimiya, Ms. Yamazaki, Ms. Seaman and Mr. Berridge by Examiner Anderson at the July 1 interview are appreciated. The reasons presented at the interview as warranting favorable action are incorporated into the remarks below and constitute Applicants' record of the interview.

Further, Applicants thank the Examiner for his helpful suggestions regarding claim amendments. Applicants believe that the above amendments embody the suggestions made by the Examiner during the July 1 personal interview.

I. Background of the Invention

Monocrystalline solar cells currently account for only about 200 MWatts of energy per year. To put this in perspective, one atomic reactor produces about 1.5 GWatts (1,500 MWatts) per year. The United States currently consumes about 1,000 GWatts of energy per year, and Japan consumes about 200 GWatts of energy per year.

Because solar cells can only utilize light in the wavelength range of about 0.35-1.1μm, silicon single crystal solar cells have a theoretical efficiency of only about 28%. Currently, some fifty years after the invention of semiconductor solar cells at Bell Laboratories, commercial solar cells are made from silicon single crystals containing boron as the dopant that controls resistivity of the crystals, and still reach an efficiency of only 16-17%, in sizes ranging from 100-150 cm^2.

As explained by Dr. Abe, Applicants decided to look for a way to dramatically increase the use of solar cells in order to preserve natural resources and the environment and facilitate energy independence. The solution Applicants chose to pursue was to increase the efficiency, the area (thus increasing the productivity and lowering the cost) and the lifetime of solar cells. Generally, however, it was understood in the art that increasing the area decreases the efficiency and lifetime of solar cells.

In spite of the lack of guidance in the prior art, Applicants have produced silicon single crystals for solar cells with a large area and increased efficiency and lifetime. In particular, Applicants have unexpectedly found that a highly efficient, low cost, long lifetime silicon single crystal for a solar cell can be achieved by the combination of:

1. producing the crystal according to the Czochralski method;
2. adding gallium as a dopant that controls resistivity of the crystal;
3. using the gallium in an amount that produces a resistivity of 0.1 to 5 $\Omega\cdot$cm (claims 20, 22, 24, 27-43, 45, 46 and 48), or 5×10^{17} atoms/cm^3 to 3×10^{15} atoms/cm^3 (claims 21, 44, 47 and 49);
4. forming the single crystal with a diameter of four inches or more; and
5. using the single crystal for a solar cell.

Nothing in the prior art suggests such a combination, or that it would produce a useful product, much less the far superior product achieved by Applicants as recognized by those of skill in the art.

The combination of all of these limitations is important in the claimed invention. For example, it was known to produce improved lifetime boron doped crystals using the Floating Zone (FZ) method rather than the Czochralski method, but the FZ method was incapable of producing such crystals in large diameters or at low cost. It was disclosed that gallium could be used as a dopant in solar cell crystals, but not that it could be used with large diameters or

with improved conversion efficiency, and it was not known that Applicants' claimed resistivity range/amount of gallium would produce the surprising peak in conversion efficiency demonstrated in specification Figure 4. Indeed, the prior art taught that use of gallium as the dopant in solar cells was "unrealistic." It was known that electronic grade crystals could be formed with diameters of four inches or more, but not that solar cell crystals could be formed with such large diameters and still have adequate, much less improved, efficiency and lifetime. Thus while bits and pieces of the invention were present among disparate teachings of various references in the prior art, there was no suggestion in the art that all of the limitations of the present claims could or should be combined, that their combination would have even a reasonable likelihood of success, or that their combination would produce the important and unexpected results achieved by Applicants. To the contrary, the prior art taught away from combination of the features of the claimed invention. Certainly, nothing in the prior art taught that the claimed combination could achieve the major increase in light conversion efficiency reflected in Figure 4 of the present specification, which moves solar energy farther than ever before into the realm of commercially practical alternative energy sources.

The significance and unexpectedness of the results of the claimed combination is unambiguously demonstrated by the award discussed in paragraph 6 of Dr. Abe's Declaration of record. In an international conference of the leading scientists in the world in the area of solar cell technology (Photovoltaic Science and Engineering), the paper disclosing Applicants' invention received a special award for excellence given to the best research paper presented at the conference. Such industry acclaim constitutes clear, objective and unambiguous evidence of the non-obviousness of the claimed invention to those of the highest skill in the art, much less to those of ordinary skill in the art.

II. The References

Section 103 requires a consideration of the claimed invention as a whole and the prior art as a whole in making an obviousness determination. This involves considering the scope and content of the prior art, the differences between the prior art and the claims at issue, the level of ordinary skill in the art, and any secondary considerations that may be present. Graham v. John Deere, 383 U.S. 1, 17, 148 USPQ 459, 467 (1966). Combination of references to support a rejection requires a motivation or suggestion in the art that one should carry out the claimed invention, and would have a reasonable expectation of success in doing so. In re Vaeck, 947 F.2d 488, 493, 20 USPQ2d 1438, 1442 (Fed. Cir. 1991). Evidence of secondary considerations such as unexpected results, including such evidence in the specification, must be taken into account. MPEP §2144.08 II. A.

A. Izunome

The Izunome patent is not directed to making any improvements in solar cell technology, and in fact Izunome makes no reference to solar cells. Izunome is directed to the problem of providing uniform impurity distribution throughout a silicon single crystal. Izunome's solution was to add gallium to a boron-doped melt, or boron to a gallium-doped melt, to control the heat expansion coefficients and suppress temperature deviation just below the interface of crystal growth. Accordingly, Izunome does not address the problem addressed by Applicants, and provides no suggestion that such a problem could be solved by any of its teaching.

In addition, the resistivity of Izunome's crystals is disclosed to be in the broad range of 0.001-10 Ω·cm. Thus Izunome provides no suggestion of the critical resistivity range of claims 20, 22, 24, 27-43, 45, 46 and 48. Nor does Izunome suggest that there may be any peak in efficiency arising from selection of a resistivity within that range when gallium is the resistivity-controlling dopant, as unexpectedly established by Applicants and demonstrated in

specification Figure 4. In particular, Figure 4 shows conversion efficiency values (a variable not even contemplated by Izunome) just inside and just outside the claimed range. While Izunome's range encompasses a lower area as much as two orders of magnitude below the lower end of the claimed range, Figure 4 includes data points showing that even going just below the claimed range drops the conversion efficiency by over a full percentage point (a very important difference when the theoretical efficiency is just 28%). Similarly, while Izunome's range encompasses an upper area as much as twice as high as the upper end of the claimed range, Figure 4 includes data points showing a loss of as much as two full percentage points of conversion efficiency by going outside the claimed range. Indeed, Figure 4 shows that by staying within the claimed range in the claimed combination, conversion efficiencies never before achieved in the prior art can be obtained. Such data clearly establishes that the differences in results are unexpected and significant, and thus that the claimed invention would not have been obvious. See MPEP §716.02(b).

Similarly, Izunome discloses that gallium may be present in an amount of 1×10^{18} - 5×10^{20} atoms/cm^3. This is well above the range of claims 21, 44, 47 and 49, in which the resistivity is controlled by the gallium. It also provides no suggestion that improved solar cell technology can be achieved by using the claimed gallium content in the claimed combination.

The Examiner has correctly pointed out that the present claims do not exclude the presence of boron from the claimed crystals. Any suggestion to the contrary in Applicants' prior arguments is respectfully withdrawn. However, it is respectfully submitted that, as discussed at the interview, this fact does not detrimentally affect the non-obviousness of the claimed invention.

As discussed at the interview, silicon single crystals used for solar cell applications are produced from the material from "cone" and "tail" crystal portions that are byproducts of production of electronic grade crystals. Thousands of tons of such material are produced

every year. This material includes boron, but not at levels sufficient to control the resistivity of crystals of the claimed invention. The limitation that gallium is the dopant that controls resistivity in the claimed invention establishes that gallium is present in a greater effective amount than is boron.

Thus, the present invention minimizes the adverse effect of any boron that may be present, capitalizes on the combination of large size, improved lifetime and high conversion efficiency achieved according to the invention, while still accommodating the reduced cost arising from use of cone and tail byproduct materials. For example, for a given resistivity level, the claimed invention produces unexpectedly improved lifetime and conversion efficiency; conversely, for a given lifetime, conversion efficiency is unexpectedly improved.

Additionally, the Izunome crystals have a three inch diameter, smaller than the at least four inch diameter of the claims. There is no suggestion in Izunome that larger diameter crystals for use in solar cells could be prepared with any reasonable expectation of success, much less that they could achieve the unexpectedly improved results for solar cells achieved by the claimed combination.

B. <u>Wolf</u>

Wolf was cited to show that it was known to prepare large diameter silicon single crystals. However, there is no suggestion or motivation in Wolf to modify Izunome and/or any of the other references to make the claimed combination or thereby achieve the unexpectedly improved results of the claimed invention that make solar cell technology so much more commercially feasible.

Wolf is a 1986 textbook, teaching generally the subjects of silicon single crystal growth and wafer preparation by the Czochralski and floating-zone methods for electronics-grade silicon, not solar cell silicon single crystals. Wolf provides no suggestion that a crystal for use in a solar cell should be made with the disclosed diameters with any reasonable

expectation of success. The understanding of the art was that solar cell conversion efficiency generally decreases as the area of a wafer increases, for example because of increased oxygen content and increased planar resistivity. See paragraph 7 of the Abe Declaration of record. However, Wolf only addresses the increase of diameters of crystals as a handling issue. Thus Wolf provided no hint that single crystals for solar cells could be successfully prepared in the claimed combination.

Furthermore, Wolf makes no reference to gallium-doping or the unexpected peak conversion efficiency/resistivity range that is also lacking from Izunome.

Thus Wolf fails to overcome any of the deficiencies of Izunome, or to provide any motivation for its combination with Izunome and/or any of the other applied references to achieve the claimed combination or the unexpected results achieved thereby.

C. Ravi

Ravi is completely irrelevant both to the claimed invention and to Izunome and the other references. It was cited for the alleged teaching of high conversion efficiency in a Ga doped CZ single crystal with a resistivity between 0.1 and 5 Ω·cm. However, it provides no such teachings, and provides no motivation for any modification of the teachings of Izunome alone or in any combination of the applied references.

Ravi contains no disclosure of gallium doping of any crystals, and no disclosure of conversion efficiency of such crystals. It contains no disclosure of CZ crystals, instead relating to hollow tubular crystals sliced longitudinally into ribbons rather than wafers. Ravi teaches the same wide resistivity range as Izunome, 0.001-10 Ω·cm, and like Izunome provides no hint of the unexpected conversion efficiencies achieved with the resistivity range of claims 20, 22, 24, 27-43, 45, 46 and 48. Because it does not disclose gallium doping, it provides no hint of the claimed gallium dopant concentration range. Furthermore, not only does Ravi teaches a smaller diameter, 2 inches, than the claimed 4 inch or greater diameter,

but there is no suggestion that diameter is of any relevance in view of the fact that the disclosed crystal is in the form of a thin-walled tube that is sliced into ribbons before use.

Thus Ravi fails to overcome any of the deficiencies of Izunome, or to provide any motivation for its combination with Izunome and/or any of the other applied references to achieve the claimed combination or the unexpected results achieved thereby.

D. Minahan

Minahan was cited as disclosing that gallium doped wafers are useful in solar cells. However, Minahan fails to overcome the deficiencies of Izunome and the other applied references.

Minahan is directed to comparing the tolerance to fluence levels of boron- and gallium-doped Floating Zone and Czochralski solar cells. Minahan fails to recognize any distinctions between controlling resistivity with a boron dopant and controlling resistivity with a gallium dopant in Czochralski silicon single crystals. While Minahan notes gallium dopant induced resistivities of "about 0.1 $\Omega\cdot$cm" and about 10 $\Omega\cdot$cm, the actual value that Minahan uses for "about 0.1 $\Omega\cdot$cm" is 0.07 $\Omega\cdot$cm (see Table 2), which Applicants' Figure 4 shows produces significantly inferior results. Thus Minahan has no recognition of the special resistivity range discovered by Applicants, and even implies, in tables 3(a) and 3(c), that 10 $\Omega\cdot$cm is good enough for solar cell purposes. No specific gallium concentrations are disclosed at all.

Furthermore, Minahan notes that problems relating to high oxygen content arise from the Czochralski process. Rather than teaching modification of such a process to achieve the present invention, however, Minahan teaches directly away from the claimed invention. In particular, Minahan suggests that the solution lies in selecting a non-Czochralski process, and not in preparing Czochralski crystals doped with gallium in the claimed amounts and with the

claimed diameter. Thus any combination of Minahan with the other references would have led one of ordinary skill in the art away from the claimed use of a Czochralski crystal.

In addition, Minahan focuses on small, two inch diameter silicon single crystals. It provides no suggestion that larger crystals could successfully be prepared for use in solar cells. Particularly in view of the fact that oxygen content was known to tend to increase with increased crystal size in Czochralski crystals, Minahan would also have led one of ordinary skill in the art away from the claimed invention in this aspect too.

Thus Minahan also fails to overcome any of the deficiencies of Izunome, or to provide any motivation for its combination with Izunome and/or any of the other applied references to achieve the claimed combination or the unexpected results achieved thereby.

E. Schmidt

As noted above, the §103 analysis must take into account the prior art as a whole. Schmidt, submitted by Applicants in their June 4, 2003, Information Disclosure Statement, notes that boron is problematic in forming crystals having a long lifetime, and discloses the possibility of using gallium in solar cell crystals. However, it too failed to recognize the peak conversion efficiencies that could be achieved by working with the claimed amount of gallium, or to disclose any experimental data at a data point within the claimed range that might have exposed the special nature of the claimed range. It not only failed to teach, but taught away from, the possibility of making improved, large solar cell crystals by using the claimed combination with at least four-inch diameter crystals. Thus, Schmidt taught that gallium-doped crystals are "unrealistic," and that the solution lies in converting to n-type Czochralski silicon rather than p-type Czochralski silicon, or in controlling the boron concentration, oxygen concentration or the resistivity of silicon single crystals whose resistivity is controlled with a boron dopant. See page 5.

Thus Schmidt further confirms that the prior art as a whole taught away from the claimed invention. Nothing in any of the references taught that the individual bits and pieces of the claimed invention should be extracted from the various references, or that combination of all of the elements of the claimed invention should be achieved or would have had a reasonable likelihood of success. Thus the claimed invention would not have been obvious over the references.

F. The Level of Skill in the Art

The level of skill in the art is reflected in the references and in Dr. Abe's declaration. Thus while those in the art had good skill levels, they also considered solar cell conversion efficiency to decrease with increased wafer size, and considered the use of gallium as a dopant unrealistic in solar cell technology. They were unaware of the peak in conversion efficiency that Applicants discovered could be achieved in combination with long lifetime and large diameter by selecting the conditions recited in the present claims. They believed that the way to improve solar cell semiconductors was to adjust boron content or oxygen content, move to n-type semiconductors, or move away from the Czochralski process altogether. Given this level of skill in the art, they had no motivation, and received none from the references, to pick and choose isolated teachings of prior art directed to different problems and solutions to construct the claimed combination with its unexpectedly superior results. To the contrary, when presented with Applicants' invention, rather than proclaiming it obvious, they presented Applicants with an international award for the excellence of their paper. Thus the evidence of the level of ordinary skill in the art further confirms the non-obviousness of the claimed invention.

III. Secondary Considerations

As noted above, the unexpected results have been confirmed by the specification and the Declaration of Dr. Abe (submitted on June 4, 2003). Industry acclaim has been

confirmed by the paper award (also submitted June 4, 2003) that Dr. Abe et al. received at an international conference of photovoltaic scientists and engineers. The unexpected improvements in solar cell efficiency, size and life are very significant in making solar technology much more competitive with conventional power technology.

After 50 years of silicon semiconductor solar cell development, none of the references connect gallium to the ability to achieve large diameter solar cells. No reference, or combination of references, teaches the peak in conversion efficiency that can be achieved by doping with gallium, or that such conversion efficiency can be achieved in large diameter crystals with long lifetimes.

The prior art as a whole teaches away from the claimed invention, and merely discloses disconnected bits and pieces, with no motivation to combine them. The prior art as a whole fails to raise the expectation that the claimed combination would work, much less provide the unexpected results of the claimed invention that make solar power more accessible.

Thus the secondary considerations evidence that must be considered in this case also confirms the non-obviousness of the claimed invention.

IV. Conclusion

In view of the foregoing, it is respectfully submitted that this application is in condition for allowance. Favorable reconsideration and prompt allowance of claims 20-22, 24 and 27-49 are earnestly solicited.

Should the Examiner believe that anything further would be desirable in order to place this application in even better condition for allowance, the Examiner is invited to contact the undersigned at the telephone number set forth below.

Respectfully submitted,

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WPB:JMS/amw

Attachment:
Request for Termination of Suspension of Action

Date: July 22, 2003

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